Diagnostic Accuracy of Diffusion Tensor Imaging for Pediatric Cervical Spinal Cord Injury

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Background and Objective

We have recently reported that Diffusion Tensor Imaging (DTI) data of the cervical spinal cord can be reliably obtained in typically developing children and children with spinal cord injuries (SCI) using inner Field-of-View imaging, and that DTI indices show moderate to good concurrent validity against MRI and clinical endpoints (International Standards for Neurological Classification of SCI, ISNCSCI)[1,2]. Sacral sparing endpoint, particularly, is important in determining ASIA Impairment Scale (AIS) designation, conversion from complete to incomplete injury but is difficult to evaluate in children [2,3]. The purpose of this study was to evaluate the predictive validity of DTI by examining its diagnostic accuracy for pediatric cervical SCI. This was performed by evaluating the specificity and sensitivity of DTI for the ISNCSCI clinical endpoints and MRI level of injury. To our knowledge this study is the first to report diagnostic accuracy of DTI in children with SCI.

Methods & Materials

A total of 35 subjects were scanned using a 3.0T MR scanner: 25 control subjects (mean age 13.4±3.9) and 10 patients (mean age=13.5±4.6) with cervical SCI. Subjects and their parents provided written informed assent and consent. Diffusion tensor images were acquired using an inner Field-of-View pulse sequence[4] to cover the cervical spinal cord (C1-T1). DTI parameters included: 20 directions, b=1000s/mm^2, voxel size=1.2x1.2x3mm^3, axial slices=35-45, TR=6100-8000ms, TE=115ms, averages=3 and TA=7min. Conventional T1 and T2 weighted scans were also obtained. Anesthesia, cardiac and/or respiratory gating were not used. Motion correction of the DTI images was performed using Automatic Image Registration. Tensor estimation was done using MedINRIA. DTI indices (FA, AD and RD) were extracted from regions of interest drawn at axial slice locations along the cervical spinal cord. Structural MRI findings for each level of the cord were classified as "normal" or "abnormal" by a board certified neuroradiologist. Findings were considered abnormal if there was increased intramedullary signal on the fast Spin Echo T2-weighted images with or without associated cord atrophy. The MRI level of injury was identified by locating the transition point from normal to abnormal. The patients were evaluated using the ISNCSCI. They underwent examination of muscle strength, sensation and sacral sparing. Mean values were compared by group (controls, SCI with intact clinical endpoint, SCI with absent clinical endpoint) and by region of the cervical cord (motor level, MRI level and cervical region above and below motor and MRI level of injury) using analysis of variance (ANOVA) for repeated measures. The clinical endpoints used to group subjects with SCI were anal contraction (AC), deep anal pressure (DAP) and S4-5 sensation. Single and multiple variable logistic regressions were used to analyze DTI parameters as predictors of deep anal pressure and voluntary anal contraction and S4-5 sensation and for the motor level and MRI level of injury. Specificity, sensitivity, receiver operating characteristics area under the curve (ROC AUC) and corresponding 95% confidence intervals (CI) were calculated. Resampling methods were used to validate the estimates from the final models.

Results & Conclusion

Controls showed mean ± standard deviation FA=0.54±0.11, AD=1.00x10^{-3}mm^2/s±0.18, RD=0.39x10^{-3}mm^2/s±0.12 and patients showed FA=0.28±0.10, AD=1.15x10^{-3}mm^2/s±0.28, and RD=0.80x10^{-3}mm^2/s±0.27. There were significant differences in FA between the control group, SCI group with intact sacral sparing and SCI group with absent sacral sparing ($p<0.003$ adjusted). AD values were significantly different among the control group, SCI group with anal contraction and SCI group without anal contraction ($p<0.003$ adjusted). However, for the remaining comparisons of both AD and RD, differences were significant only between the control group and SCI group with absent Deep Anal Pressure and S4-5 sensation ($p<0.003$ adjusted). There was a strong association between FA, AD, RD, anal contraction, deep anal pressure, S4-5 sensation, MRI findings and severity of injury. Univariate analysis indicated FA to be the strongest overall predictor of each clinical endpoint. However, DTI values in combination showed strongest diagnostic accuracy for predicting the presence of anal contraction (AD and RD), deep anal pressure (FA), S4-5 sensation (FA, RD), motor level (FA, AD and RD) and MRI level (FA, AD and RD) (Table). Bootstrap and Jackknife median values indicated consistency of the parameter estimates. Overall, the predictive accuracy of DTI for sacral sparing endpoints and motor and MRI level of injury was good to strong. In conclusion, our observation that FA values differ between subjects with SCI who have sacral sparing and those who do not have sacral sparing is novel and has important clinical relevance as this endpoint has received recent attention with respect to its validity and reliability in children[2,3].

Table: Multivariate Analysis showing specificity, sensitivity, ROC AUC and 95% CI of DTI values for AC, DAP, S4-5 sensation, motor level and MRI Level.

	Predictor	Specificity (95% CI)	Sensitivity (95% CI)	ROC AUC (95% CI)
Anal Contraction (AC)	AD,RD	0.74 (0.71,0.77)	0.80 (0.75,0.84)	0.93 (0.91,0.94)
Deep Anal Pressure (DAP)	FA	0.53 (0.50,0.56)	0.70 (0.60,0.79)	0.88 (0.85,0.90)
S4-5	FA,RD	0.81 (0.78,0.83)	0.80 (0.75,0.85)	0.93 (0.92,0.95)
Motor Level	FA,AD,RD	0.67 (0.65,0.70)	0.85 (0.78,0.90)	0.92 (0.91,0.94)
MRI Level	FA,AD,RD	0.83 (0.80,0.85)	0.89 (0,84, 0.93)	0.92 (0.90,0.94)

References

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